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Fire and Plastics in Buildings

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FIRE AND PLASTICS IN BUILDINGS

by

G R Basson

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G. R. Basson.

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FIRE AND PLASTICS IN BUILDINGS

by G R BASSON*

INTRODUCTION

Synthetic polymers, generally known as plastics, are finding an increasing number of uses in buildings. This can increase the fire risk because many of these materials ignite more easily, burn faster and develop more smoke and potentially toxic gases than traditional materials. If potential hazards from their use are to be avoided, the fire properties of some of the commoner plastics must be more widely known to ensure their safe use in buildings.

COMPOSITION AND FIRE PROPERTIES OF PLASTICS

The fire properties of plastics depend on:

- (a) The physical nature of the product. Expanded plastics, for example, have a high surface to mass ratio and will generally burn faster than the same material in a denser form.
- (b) The nature and quantities of fillers and additives. These are added to polymers to improve appearance (dyes and pigments), to increase flexibility (plasticisers), for mechanical strength (reinforcing fibres), to decrease the cost (inert fillers) and to retard burning (fire retardants).
- (c) The conditions within the fire. Oxygen concentration, and temperature are examples of these variables.
- (d) The chemical composition and bonding of the polymer.

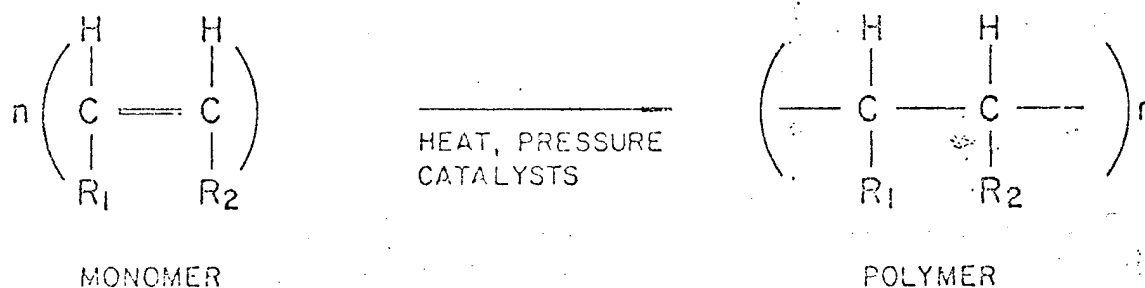
*Senior Chief Research Officer, Fire and Concrete Engineering Division
National Building Research Institute, Council for Scientific and Industrial
Research

Some knowledge of the chemical composition and structure of polymers is necessary for a better understanding of the fire behaviour of these materials.

Plastics contain organic substances of large molecular mass, called polymers, which are formed through a process called polymerisation. In polymerisation smaller molecules or monomers are combined by chemical reaction to form large molecules consisting of hundreds or thousands of linked monomer molecules.

One simple form of polymerisation occurs through the rearrangement of bonding between the carbon atoms in cases where the monomer has double bonds.

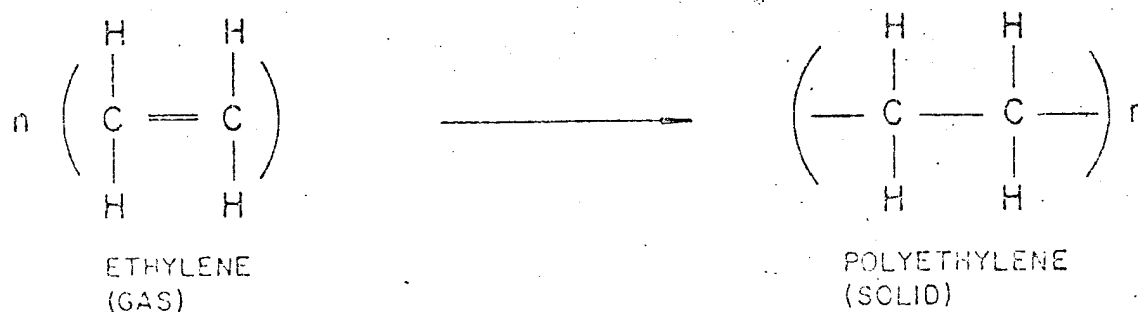
This may be depicted as follows:



Some of the more widely used polymers of this type are:

Polyethylene

Polyethylene is formed through the polymerisation of ethylene gas:



Polyethylene is used extensively as a roof underlay for tiled roofs, for vapour barriers and waterproofing membranes and for covers around fibrous insulating materials such as glass- and mineral wool blankets.

The material is thermoplastic which means that it softens and melts on exposure to heat, and solidifies on cooling to normal temperatures, without any chemical change taking place. When exposed to temperatures above its

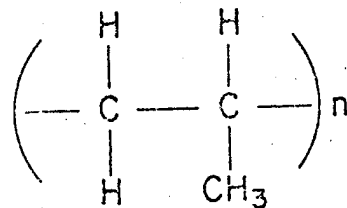
decomposition temperature, however, chain scission takes place, that is the polymer unlinks with the formation of the original monomer and of longer chain hydrocarbons ranging from liquids to waxes. Ethylene is highly flammable and polyethylene therefore burns rapidly. Burning molten waxy products drip off and can ignite combustible materials onto which they drip.

As polyethylene contains only carbon and hydrogen, the gaseous combustion products consist mainly of carbon monoxide, carbon dioxide and water vapour and are regarded as no more toxic than the combustion products of wood and other cellulosic materials.

When used as a sleeve over mineral wool blankets, the material will propagate fire even when very thin sleeves are used.

Polypropylene

Polypropylene is chemically and structurally closely related to polyethylene and the structural formula is written as:

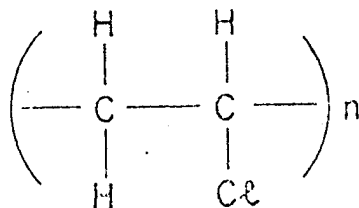


Polypropylene is mainly used in the form of textile fibres for carpeting, or fabrics. It is also used for water pipes.

The material is thermoplastic and has very similar fire properties to polyethylene. When a polypropylene carpet is glued to a concrete floor, heat absorption by the floor will be such as to inhibit combustion and prevent the fire from spreading along the carpet. However when fitted over an insulating underlay the fire may spread.

Polyvinyl chloride

Polyvinylchloride, or PVC as it is generally known, is one of the most widely used plastics. It is structurally closely related to polyethylene and the structural formula is written as:



In buildings it is used in floor tiles, in wall linings, in the insulation material for electrical wires and cables, and, in an unplasticised form, as soil, waste and vent pipes.

Because the material contains chlorine, it produces hydrogen chloride gas on thermal decomposition and during combustion. Since most fire gases also contain water vapour, the two combine to form hydrochloric acid.

Hydrochloric acid is strongly corrosive and hydrogen chloride gas is highly irritating and toxic when inhaled. Expensive losses are often incurred as a result of the corrosive action of hydrochloric acid on electrical contacts during a fire. The corrosion of reinforcing steel has been known to cause extensive damage which in some cases only became apparent a year or more after the fire.

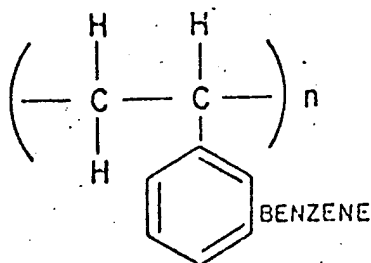
The fire-stopping of electrical and plumbing service ducts, particularly where they penetrate fire walls, is an important requirement as far as the control of both fire and fire gases is concerned.

In the case of PVC pipes and conduits of up to 40 mm in diameter, intumescent grades of PVC are available. These compounds form a voluminous char on exposure to fire which blocks off any openings in trunking through the wall. Where the pipes are larger than 40 mm metal sleeves, or spring or gravity activated shut-off devices are sometimes used. The latter method is especially useful in the case of pneumatic conveyor tubes. Gravity and spring activated devices rely on the fact that the material from which the tube is made, will soften in a fire and can be mechanically collapsed to seal the opening.

Polystyrene

Expanded polystyrene in board and bead form is extensively used as a thermal insulating material in buildings.

The structural formula of the polymer is:



Polystyrene is thermoplastic and softens at a temperature as low as 110 °C, which is far below its ignition temperature of 400 to 500 °C. This property is important where the thermal insulation of industrial ceilings is concerned, because, when suspended on metal T-supports, polystyrene boards will soften and fall unignited to the floor, rather than spread the fire at ceiling level.

Panels in which polystyrene is sandwiched between layers of sheet metal should not be used in any loadbearing situation since an outbreak of fire can cause their rapid structural collapse.

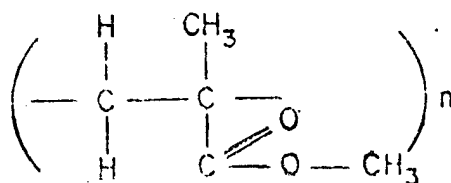
Tests are being conducted at the National Building Research Institute (NBRI) to quantify the fire risk associated with the use of expanded polystyrene for thermal roof insulation. Two sources of ignition are being investigated; the first a timber crib located on the floor below a conventional ceiling and the second a simulated electrical short-circuit in the roof space.

The gaseous combustion products of polystyrene consist of carbon monoxide, carbon dioxide and water vapour. Low temperature thermal decomposition can yield some styrene monomer which is both toxic and irritating, but in a fire the monomer will normally burn.

Because of the presence of the benzene ring in polystyrene, combustion is less complete than in the case of straight-chain hydrocarbons and a lot of black smoke consisting of unburnt carbon particles is produced.

Polymethyl methacrylate

Polymethyl methacrylate is a slightly more complex polymer with the structural formula:



It is easily ignited and burns rapidly with the liberation of a great deal of heat. Because of its thermoplastic nature, burning molten drip-offs can spread fire for example from burning roof lights to combustible materials at floor level. There is however the advantage that hot fire gases can escape through the vent formed by the destruction of the roof light.

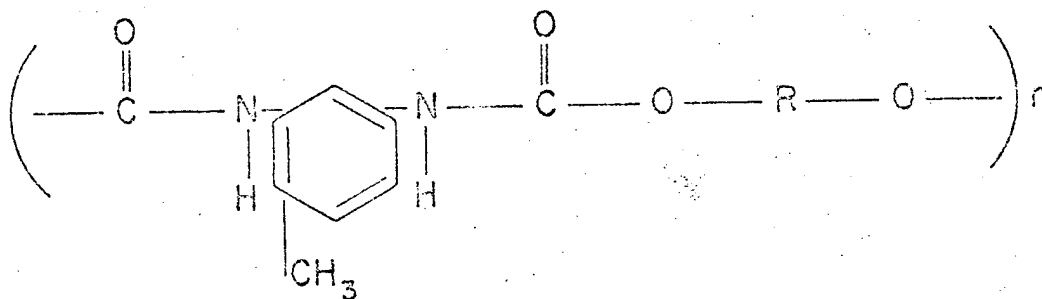
The material is thermoplastic and is readily moulded. It is being increasingly used in buildings for baths, washbasins, light diffusers, roof lights and to some extent as a safety glazing material. The use of polymethyl methacrylate for baths, wash basins and vanity slabs has increased the fire risk in a part of a building that has traditionally had a low fire risk.

The gases produced when polymethyl methacrylate burns contain mainly carbon monoxide, carbon dioxide and water and are not particularly toxic.

Polyurethanes

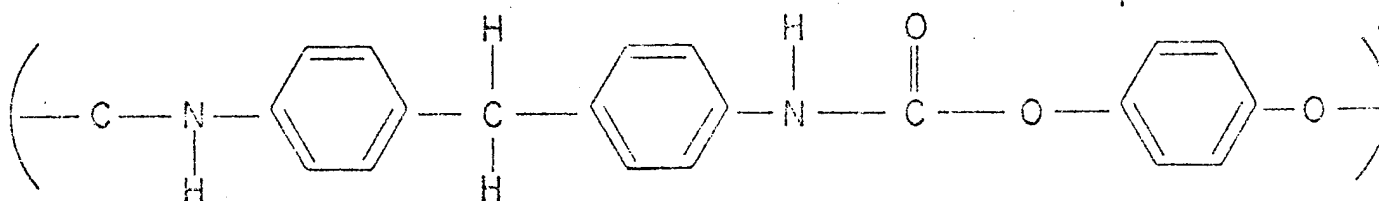
Two types of polyurethane are used in buildings, mainly in the form of foams.

Flexible polyurethane foams, of the type



are used in upholstered furniture.

Rigid polyurethane foams, of the type:



are used in sandwich panels where the good thermal insulation properties and high mechanical strength of the core material have advantages. Fire retarded grades are used in most applications overseas even though this adds to the toxicity hazard. (Most of the fire retardants used in rigid polyurethane foams are based on phosphorous-halogen compositions.) Non fire-retarded grades have

been known to spread fire in wall cavities but manufacturers of polyurethane foams have now succeeded in formulating materials that meet fire spread performance criteria based on small-scale tunnel furnace tests.

Polyurethanes contain nitrogen in their structure and apart from hydrogen cyanide (HCN) and nitrogen oxides, a wide variety of gaseous compounds has been identified in gases produced by burning polyurethane foams. Variations in both composition and amount of combustion gases depend on the type of fire retardant used, the available oxygen and the temperature of the fire.

This makes the evaluation of the toxicity of polyurethane fire gases extremely complex. Most researchers make use of animal exposure tests to evaluate toxicity and analytical methods, such as gas chromatography and mass spectrometry, to identify gases and vapours. It is, however, extremely difficult to attribute specific toxicity to a particular gaseous compound because the synergistic effect of a mixture of gases has to be considered.

Chain scission takes place under certain fire conditions with the formation of extremely toxic toluene diisocyanate (TDI) in the case of flexible polyurethane foams and highly toxic diphenyl methane diisocyanate (MDI) in the case of rigid polyurethane foams. The specific toxicity of combustion gases will be discussed later.

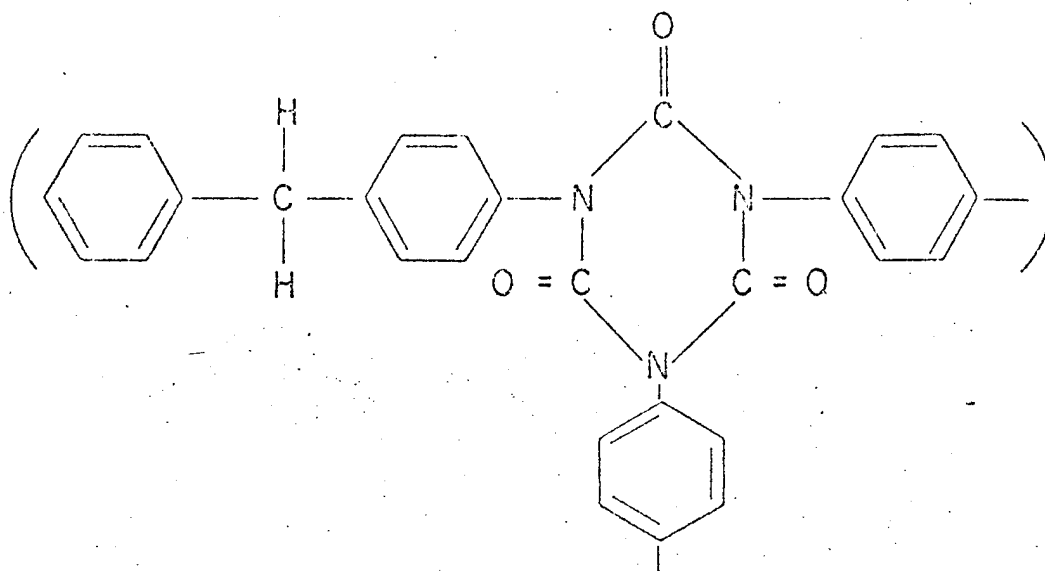
Polyurethanes burn fiercely and spread fire rapidly when used as wall linings and ceilings. A large number of deaths have occurred in overseas countries where the material was used for these purposes.

Polyurethane is thermosetting, in other words, it does not soften or melt when heated. During a fire it therefore continues to offer a large exposed surface that can burn. Very little char is formed and a polyurethane core in a panel therefore makes only a relatively small contribution to the fire resistance of the element in which it is used.

Polyisocyanurates

Ring or cyclic compounds, especially those with nitrogen in their structural backbones, have better fire properties than straight-chain polymers.

Polyisocyanurate, which is basically a modified polyurethane is one example. In this case the isocyanurates are trimerised to form an isocyanurate ring:



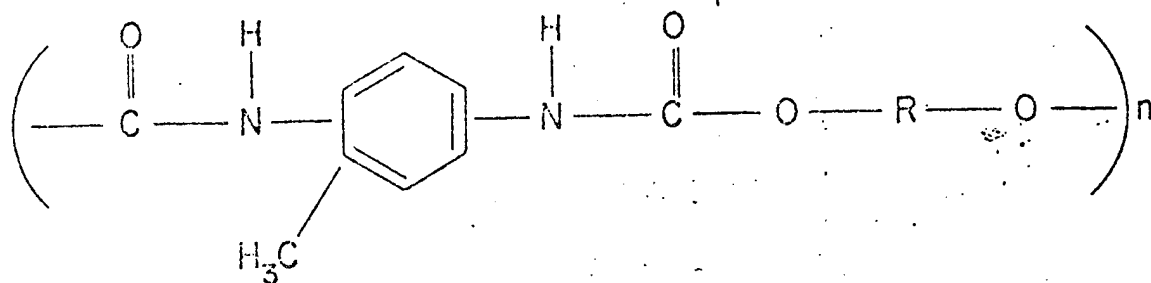
Polyisocyanurate foams, when properly formulated, exhibit little or no spread of flame and will generally be self-extinguishing. Tests conducted at NBRI have, however, shown that some polyisocyanurate foams contain large percentages of polyurethane leading to poor fire performance.

Polyisocyanurate foam does not undergo chain scission on thermal degradation and combustion. The main gaseous combustion products of the pure foam are carbon monoxide, carbon dioxide, water vapour, nitrous oxides and possibly small amounts of hydrogen cyanide. Because the material does not burn as vigorously as polyurethane, the concentrations of both gaseous products and smoke in the combustion gases are lower than in the case of polyurethanes.

A carbonaceous char with good insulating properties is formed when polyisocyanurate foams are exposed to fire. This char contributes substantially to the fire resistance of sandwich panels with polyisocyanurate cores, but wide gaps are usually formed in this char as a result of shrinkage during the charring process.

Polyester resins

Thermosetting polyester resins, used in conjunction with glass fibres for the manufacture of glass-reinforced polyester sheeting (GRP sheeting), used mainly for roofing and wall-cladding of industrial buildings are of the type:



GRP sheeting is easily ignited and burns vigorously. There is however not too much material that can burn and the contribution of GRP sheeting to the thermal radiation from a burning building can be regarded as negligible compared to that of the normal fire load.

GRP sheeting does not have any fire resistance and the area of GRP sheet cladding on a building is treated in the same way as windows or openings in the calculation of the minimum distances required between buildings to prevent fire spread caused by radiation.

Although polyester resins can be fire-retarded to make them less easily ignitable and to slow down the rate of burning, the durability and weather resistance of transparent or translucent grades of GRP are seriously impaired by the incorporation of fire retardants. It is therefore more advantageous to use normal grades of GRP sheeting and to design cladding and roofing with adequate fire breaks to limit the spread of fire.

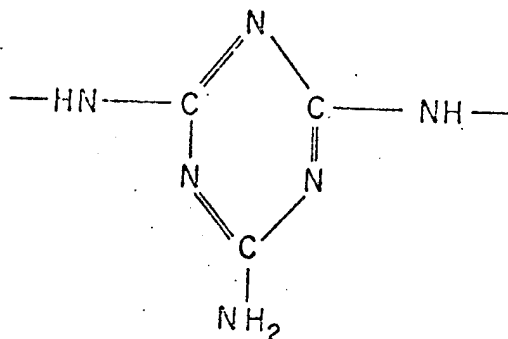
The gaseous thermal decomposition and combustion products of polyester resins are not regarded as being very toxic but copious quantities of black smoke are produced.

Other synthetic polymers

It is clear from the foregoing that the range of synthetic polymers is almost unlimited. New ones are developed almost daily and many are designed to suit applications in the building industry.

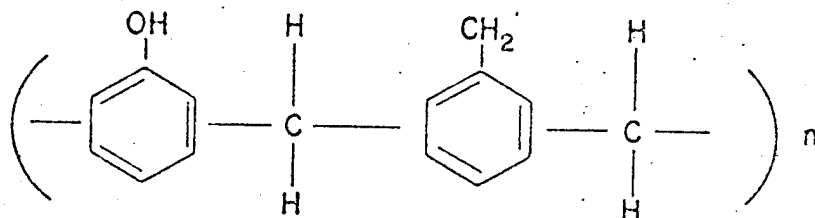
Polymers that are used less extensively but which have reasonably good fire properties are:

Melamine resins of the type:



These are used mainly in the form of impregnated paper laminates for decorative and protective applications such as table tops.

Phenolic foams related to "Bakelite" and of the type:

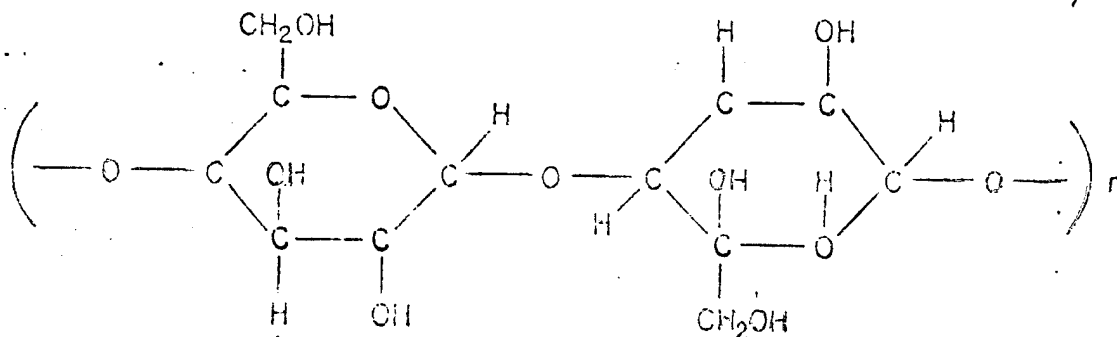


These are used as insulating materials. The physical properties such as mechanical strength and abrasion resistance of these foams are generally poorer than those of polyurethane and polystyrene foams.

Urea formaldehyde is a polymer foam with fairly good fire properties. It used to be used extensively overseas but its use has now been restricted because under certain conditions formaldehyde can be liberated.

Natural polymers

A natural polymer with very wide application in buildings is cellulose present in wood, paper and other cellulosic products. The structural formula of this polymer can be written as:



The fire propagation characteristics of cellulosic products are well known and need not be dealt with here.

What is of more importance however is that the gaseous thermal decomposition and combustion products of cellulosic materials are not as simple as is generally accepted. Apart from the usual carbon monoxide, carbon dioxide and water vapour, a complex range of gases or vapours such as acetic acid and acrolein are formed. Though combustion gases are not regarded as "highly toxic", suffice it to say that if cellulose were a synthetic material, manufacturers would encounter a lot of market resistance to its use.

FIRE TESTS ON PLASTICS

Most modern building regulations are based on performance criteria which rely on one or more test methods to define a set of desired properties rather than prescribing particular materials or components.

Although this approach is theoretically sound, performance criteria are generally based on laboratory-scale tests giving reproducible results. These small-scale test results seldom adequately represent the materials' behaviour in a real fire.

It is not possible to mention all the test methods used to evaluate the fire performance of materials, but a broad outline of some laboratory test methods and their limitations is given.

Fire tests are aimed at:

- (a) determining the basic fire properties of materials,
- (b) determining a fire resistance rating for building components.

Tests to determine the fire resistance rating of building elements will not be dealt with.

Tunnel furnaces, in which the material to be tested is fixed to the roof or floor of the tunnel, are used in North America to evaluate flamespread properties. Although smoke development and heat or fuel contribution can also be determined in a tunnel furnace, other methods give more meaningful results.

The National Bureau of Standards (NBS) smoke density chamber, for example, is being increasingly used for the determination of smoke development and, in conjunction with analytical methods such as gas chromatography, for the qualitative and quantitative analysis of gaseous combustion products. However, in many cases large-scale mock-up tests give completely different results and many fire hazardous applications would result, were the laboratory tests to be used on their own.

Most fire deaths are caused by suffocation or by the inhalation of toxic gases. The presence of carbon dioxide in fire gases in concentrations above approximately 10000 mg l^{-1} increases the rate of breathing and, if toxic gases are present at the same time, the inhalation of these is increased. Depletion of the oxygen content of the air from the normal 20 per cent to around 17 per cent also has the effect of increasing the rate of respiration.

The combustion gases that can be formed by burning or thermally decomposing plastics can to a certain extent be predicted from a knowledge of their chemical composition and bonding. Though the specific effects of many gases and vapours on humans are known, it is more difficult to evaluate the effects of mixtures of gases.

Some fire gases cause diminishing muscular coordination or incapacitation through their anaesthetic action. In the case of strong irritants such as formaldehyde, hydrogen chloride, or hydrogen fluoride, oedema of the lungs is caused which may result in delayed death.

As far as can be established there are at present no performance criteria governing the use of materials generating toxic gases on exposure to fire. As a guideline, the data given in Tables 1 and 2 can be used to give an indication of the potential toxicity of some of the new building materials in a fire.

TABLE 1

LETHAL GAS OR VAPOUR CONCENTRATIONS FOR HUMANS

Gas or Vapour	LC ₅₀ * mg l ⁻¹ (20 minutes exposure)
Carbon Monoxide : CO	3000
Carbon Dioxide : CO ₂	> 100000 (Asphyxia due to oxygen depletion)
Sulphur Dioxide : SO ₂	8000
Hydrogen Chloride : HCl	7000
Hydrogen Fluoride : HF	4500
Hydrogen Bromide HBr	> 5000
Hydrogen Cyanide HCN	135
Hydrogen Sulphide H ₂ S	1000
Nitrogen Oxide NO	300
Nitrogen Dioxide NO ₂	180
Ammonia NH ₃	10000
Phosgene COCl ₂	50
Chlorine	1000
TDI	± 15 (very strong irritant)
MDI	± 250
Formaldehyde HCHO	750 (oedema)
Acrolein CH ₂ = CHCHO	10 - 20
Styrene H ₅ C ₆ CH = CHC ₆ H ₅	± 1000

*The LC₅₀ value is defined as the concentration of the gas in the atmosphere that will produce death in 50 per cent of the cases on inhalation within the defined period.

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TABLE 2RESULTS OF ANIMAL EXPOSURE TESTS AT A
COMBUSTION TEMPERATURE OF 750 °C*

Material	Mass of sample (g)		Gas concentration in exposure chamber % (volume at 21 °C)			Average time to incapacitation (I) of mice (8) or death (D) min.
	Before Test	After Test	CO (Max)	CO ₂ (Max)	O ₂ Min	
Polystyrene foam	15	0,1	0,17	0,69	19,8	12,8 (I)
PVC foam	7,5	1,1	0,15	1,40	19,2	4,1 (D)
Urea resin foam	1,0	0,1	0,09	0,40	20,5	1,44 (D)
Polyurethane foam	5,0	0,2	0,14	0,90	20,0	1,47 (D)
Luan timber	10,0	2,6	>1,0	2,50	17,5	4,23 (D)

* NISHIMARU

CONCLUSION

NBRI research is aimed at the evaluation of the potential fire hazards that can be created through the use of plastic materials in buildings. The research is conducted under conditions simulating as closely as possible the intended use of the material.

For industrial applications less emphasis is placed on potential toxicity than on fire propagation risks.

In multi-storey office buildings or buildings in which people sleep, equal emphasis is placed on combustibility and the potential hazard from toxic fire gases. One recommendation in this respect is the use of so-called thermal barriers that will protect plastic foam insulating materials against thermal decomposition for specific lengths of time in a fire.

In houses it is recommended that plastic foams used as insulation or cavity fill materials should be fully protected against thermal decomposition for twenty minutes. In industrialised buildings this can often be achieved by cladding with 12,7 mm thick X-rated gypsum plasterboard or by covering with at least 30 mm of reinforced plaster, concrete or gunite.

Attention is being given to the use of plastic foam roof insulating materials. Two approaches seem feasible, one is to compartment roof voids in such a way that gaseous combustion products will be confined to the room in which the fire breaks out. The second approach is to use the thermal barrier concept but this would necessitate a totally different type of ceiling construction than that currently in use.

REFERENCE

NISHIMARU Y, SAITO F, NAKAMURU K, MORIKAWA T and YUSA S. *Evaluation of acute toxicity of smoke and gases from smouldering and burning plastic foams.* Proc 4th Joint Panel Meeting U.J.N.R. Panel on Fire Research and Safety, Tokyo, Feb 1979, pp 567-586.